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DRAINAGE ON THE FARM

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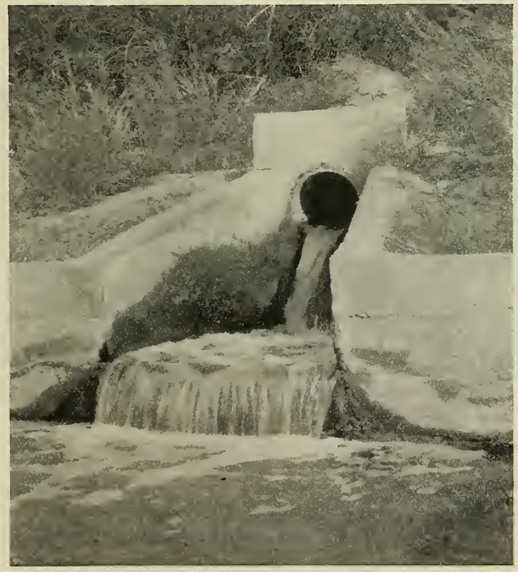

A well-built, substantial, concrete outlet protection for a tile drain.

INTRODUCTION

THIS CIRCULAR is intended to cover the principles and methods of drainage of wet lands in California and is applicable to those parts of the state which do not require the special considerations essential in the drainage of lands where alkali is a factor.

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NEED FOR DRAINAGE

Almost every farm contains some land that could be improved and made to produce more or better crops by some type of drainage. This, rather than the presence of swamps, ponds or springs, usually determines the need for drainage.

Areas with considerable slope or even hillsides do not necessarily insure adequate natural drainage, although such slopes will greatly facili-

Fig. 1.—A typical poorly drained grain field showing patches where the grain has been drowned out or stunted.

tate the correction of poor drainage conditions. The greatest need of drainage, however, occurs in flat, level areas or basins which are made up largely of heavy-textured soils or soils having relatively impervious subsoils.

BENEFITS OF DRAINAGE

There are many benefits to be derived from drainage. The most obvious is the removal of ponds and the drainage of swamps to permit the growing of crops where it would otherwise be impossible. Land of this type, however, constitutes only a small proportion of the area which could be improved. Most of the land that would be benefited by drainage can be farmed and some crop obtained without drainage. Figure 1 shows a poorly drained grain field in which part of the grain has been drowned

out. Drainage would improve the granulation or tilth. It would also improve the aeration of such land and thus raise its témperature during the early part of the season, which in turn would result in earlier development of the crops. It would also very materially reduce the effects of drought during the dry season and by quickly removing the excess of water from wet places permit the entire fields to be planted or cultivated at one time. Other benefits follow, such as the more rapid development of useful microörganisms which accelerate chemical reactions and increase the availability of plant food elements; there is less danger from frost injury and the plants are rendered less susceptible to disease or parasitic injury.

Drainage removes only the free water existing in the soil in excess of that necessary to wet it to field capacity. The removal of this excess water increases the mass of soil wetted with only capillary water. There are few useful plants which will thrive with their roots in saturated soil.

ENGINEERING ASSISTANCE

Too much stress cannot be laid on the advisability of securing reliable engineering advice before installing a drainage system. The owner rarely has the training or experience which will enable him to design and construct the best and most economical system. The designing of large comprehensive drainage systems, involving the organization of drainage districts or coöperation among a number of owners, is usually conceded to require the services of an engineer, but no less ability is often required to properly design and lay out a system involving only a few hundred feet of drain. Good engineering advice is cheaper than poor drains. The careful engineer makes a survey not only of surface conditions to determine the direction in which drains should run and the fall available, but also carefully examines the subsoil with a soil auger as an aid in determining the best location of a drain, its depth, and the proper spacing between drains. To determine the proper size of a drain for the slope and the amount of water to be removed also requires study and computation.

THE OUTLET

No system of drainage will prove entirely satisfactory or give the maximum results without a good and adequate outlet. The first step in planning for drainage is to ascertain the suitability of the outlet. If a channel which will provide free flow for the discharge of the proposed system cannot be found one must be provided. This may require very careful planning to use most advantageously all available fall. To secure an out-

let it will often be necessary to coöperate with a neighbor or obtain permission to cross other property. The ideal outlet provides a free flow from the main drain at all times and allows the construction of the main drain at a good depth (see cover picture). This does not imply, however, that unless an outlet meeting all of the ideal requirements can be secured, the proposed drainage project must be abandoned. Under certain conditions the main drains may be submerged for short periods during storms

Fig. 2.—Open drains waste valuable land, harbor weeds and injurious insects, and require considerable maintenance.

without serious damage. In the drainage of tidal marshes the outlet is frequently through tide gates which are closed for several hours each day, yet satisfactory drainage is provided.

TYPE OF DRAIN

There are two general types of drains, each of which may be modified in many ways to suit local conditions. These are the open drain, or drainage ditch, and the covered drain, or buried conduit. Covered drains are usually of tile. The type of drain selected for any particular place depends upon the requirement to be met and the wishes of the owner.

Open Drains.—Open drains have an advantage over tile where large quantities of surface water are to be removed rapidly, as, for instance, providing an outlet for runoff from a hillside during a heavy rain, or as an outlet for a large tile drain. Where large areas are drained and the

land is not of great value, the ditch is most frequently used because it carries a large amount of water more economically than tile. On the other hand, open drains constructed across a field are at best unsatisfactory; for if deep enough to drain the subsoil adequately, they require a considerable area of land which might otherwise be farmed. Often a combination of tile and open ditch is used. In this case a broad shallow ditch carries off flood waters while beneath it a tile line completes the work by draining the subsoil.

Open drains may be a source of danger to stock unless properly fenced; they may harbor obnoxious weeds, plant diseases, and rodents; and they require consistent maintenance to be always fully efficient. Figure 2 illustrates a badly obstructed open drain.

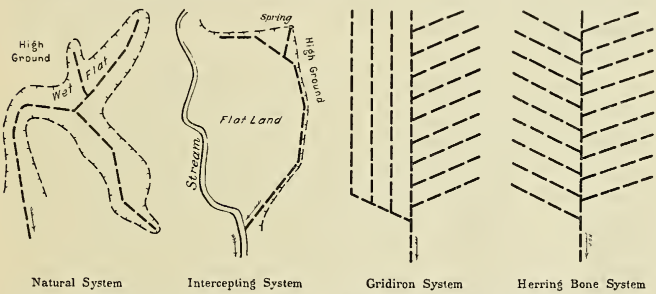

Fig. 3.—Various arrangements of drains. Frequently drainage systems as actually constructed involve a combination of two or more of these arrangements.

Tile Drains.—Tile drainage offers the most efficient and permanent method of draining land. The tile are placed underground where they do not interfere with cultivation and when properly laid require very little attention to keep them in operation. Although it is neither good engineering nor good farming to be ignorant of the exact location of underdrains, many farms are being successfully drained year after year by tile, the location or even the presence of which may not be known to those who operate the farms.

Tile drains lend themselves to more variation in layout design than do open drains because of the fact that they do not interfere with cultivation. In general there are four arrangements (fig. 3) which can be used either in the true form or in combination. There is no best arrangement for all conditions. Each field must be surveyed and studied to determine its own particular needs.

SURVEY AND PLANS

When the outlet has been decided upon, a complete survey should be made of each area that requires drainage. This survey should include all areas which will have a common outlet whether it is intended to drain them at this time or not. If only a portion of the work is to be done at one time, it should be planned with the future extensions in view. If this is not done, some portion of the work, usually the main drain, may be found inadequate to care for additional areas when they are added. As a drain is constructed, its location should be noted exactly on the plan. It is not sufficient to rely on the original plan, which is made before construction begins, for frequently minor and sometimes major changes are made during construction. All survey notes and plans should be carefully preserved, as the time may come when they will be badly needed.

DESIGN OF OPEN-DRAIN SYSTEMS

For areas up to 160 acres, drains should be designed to remove about 1 surface inch from the tract in 24 hours. If water reaches the tract from other sources, the entire contributing area should be considered rather than merely the area it is proposed to drain. For larger tracts the main drain may be designed for a runoff of only ¾ inch in 24 hours. Conditions of tilth, topography, and soil are determining factors in the rapidity and amount of runoff. In a gently sloping field in good tilth, the soil will retain much more water than in barren or untilled fields or in those having greater slopes. The size of ditch required to carry a given amount of water is dependent upon the slope or grade and, to a less extent, upon the shape of its cross section; the shape is determined by the kind of soil through which the ditch passes.

In ascertaining the size of an open drain required to carry a given quantity of water on a given grade, Elliott's formula for open drains has been found satisfactory and because of its simplicity is more convenient to use than some others, which may under certain conditions be slightly more accurate. Elliott's formula is:

$$v = \sqrt{\frac{a}{p} \times 1\tfrac{1}{2} f}$$

where v = velocity in feet per second
a = area or cross section of drain in feet
p = wetted perimeter in feet
f = fall in feet per mile
Q = quantity in cubic feet per second

When the velocity is found the quantity of water in cubic feet per second is obtained from the following formula:

$$Q = av$$

An open drain should be deep enough and wide enough to carry the maximum flow without overtopping its banks, and to carry the normal flow well below the general ground surface. The banks of the ditch should be sloped to such an extent as to prevent, as far as possible, any caving when they are wet. In clay, the side slopes may be as steep as ½ foot horizontal to 1 foot vertical, while in sandy soils it may be necessary to make the slopes as flat as 2 or more feet horizontal to 1 foot vertical. The excavated material should be placed some distance from the edge in order to prevent it from slipping back into the drain. A safe rule to follow for ditches under 20 feet in top width is to place excavated material so that the berm, or strip of land between the edge of the ditch and the toe of the waste bank, is equal to one-half the top width of the ditch (fig. 4).

Team and scraper ditches are sometimes used where surface water accumulates in considerable quantities and the drain is required simply to remove it quickly. Drains of this nature are expected to be dry most of the time and are so dug as to be of least hindrance to cultivation and cropping. In many cases cultivation is continued over such drains.

Open drains dug by hand are necessarily limited to rather small ditches, seldom over 3 or 4 feet wide on top and 4 to 5 feet deep. Ditches of this type cause the least inconvenience when located along fence or property lines. Figure 4 illustrates the relation between depth, side slopes, and width of berm for a hand-dug ditch in heavy soil.

The banks of open drains, at the points where surface water enters, must be protected so as to prevent erosion, which not only destroys the banks and wastes land but also fills up the drain and impairs its efficiency. Surface water may be admitted to an open drain through a box or culvert under the waste bank. When properly constructed, such a box will be a protection against washing of the ditch bank.

CONSTRUCTION OF OPEN DRAINS

Open drains are constructed in three ways: by machinery, by teams and scrapers, and by hand. There are several types of excavating machinery for digging open drains; these vary in size from the large floating or dragline dredge capable of excavating drains up to 100 or more feet in width, to the excavator which will dig a drain 3 or 4 feet in width. For farm drains, however, only the smaller types of excavators are used, and these only on the larger farms, or where several farmers unite in a gen-

eral plan of drainage. When drains are constructed during the dry season, teams may be used. Ditches excavated in this way are necessarily limited to rather shallow, broad drains in soils stable enough to permit the driving of teams over them. Digging drains by hand is feasible only when they are small enough to allow the excavated material to be disposed of without rehandling.

MAINTENANCE OF OPEN DRAINS

Open ditches require a considerable expenditure for maintenance. It is this item that makes the final cost of open drains equal to or above that of underdrains. In order to maintain the efficiency of a ditch, it is neces-

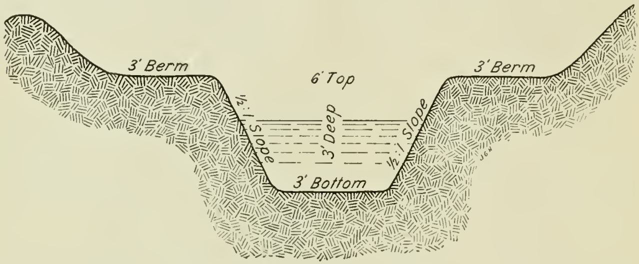

Fig. 4.—A type of hand-dug ditch suitable for heavy soils.

sary to clean it at least once each year. Brush and weeds that are certain to grow during the dry season must be removed, caving banks must be repaired, and all obstructions such as temporary fences, rubbish, etc., removed before the wet season begins. After a year or two it may be necessary to re-excavate in order to maintain the desired depth. If these things are not done, conditions may soon become as bad as they were before the ditch was constructed. The cost of maintenance, of course, varies with the amount of excavation and repair work necessary; in a few years it may amount to a considerable proportion of the first cost.

DESIGN OF TILE-DRAIN SYSTEMS

Location.—The location of the main drain will be controlled largely by the position of the outlet, the size, shape, and slopes of the area to be drained and the location and depth of the laterals. On the other hand, the location and depth of the main drain will have much to do with the location, cost, and efficiency of the lateral drains. Usually the main drain follows the lowest of the natural depressions with submains following the

minor depressions. In the natural system as illustrated in figure 5, this is all the drainage that is required.

In the foothill areas, the intercepting system is most frequently employed. Where the water comes from springs or seepage areas at the base of a hill or is known to be moving in a definite direction, a drain located either directly through the spring or just at the upper edge of the damaged land usually intercepts the water before it has reached the land it is desired to improve. In an intercepting drain sometimes the variation of a few feet one way or the other will mean success or failure. Where springs are to be drained, it is essential that their exact location be determined. A diligent use of the soil auger may reveal interesting facts regarding subsoil conditions in such areas.

Where a regular system of drains, such as the gridiron or herringbone, is required, considerable study is often necessary in order to plan a lateral system to suit the drainage requirements and at the same time be economical. One point to be observed is the elimination of all unnecessary double-drained areas. Where two drains join there is always an area from which drainage water might flow into either drain. In figure 5 the area around the junction of laterals C and B with the main drain may be said to be double-drained. A drainage system using the minimum amount of tile consistent with efficiency is usually the cheapest.

Depth.—The depth, spacing, and size of tile drains are related and interdependent subjects. The proper depth for tile varies somewhat with the texture of the soil. In sandy soils the depth may be less than in clay since the water moves more freely in sand than in clay. Deep drains will lower the water table farther than shallow ones, but it requires more time after a storm for them to function. It is well known that drainage is more effective and shows greater results after two or three years than it does the first. In medium-textured soils, drains from 3½ to 4½ feet deep are most satisfactory. Four feet is probably the most efficient average depth, though a very impervious subsoil or rock may make a lesser depth necessary.

The greater the depth of drained soil, the greater will be root penetration, feeding area, available plant food supply, and drought resistance of the crop.

Spacing.—The texture of the soil also influences the spacing or distance between laterals. Since in heavy soils the movement of water is retarded by the fineness of the soil particles, in such soils it is necessary to place drains closer together to obtain a certain degree of drainage than in a lighter soil.

Other things being equal, the greater the depth of drainage, the wider

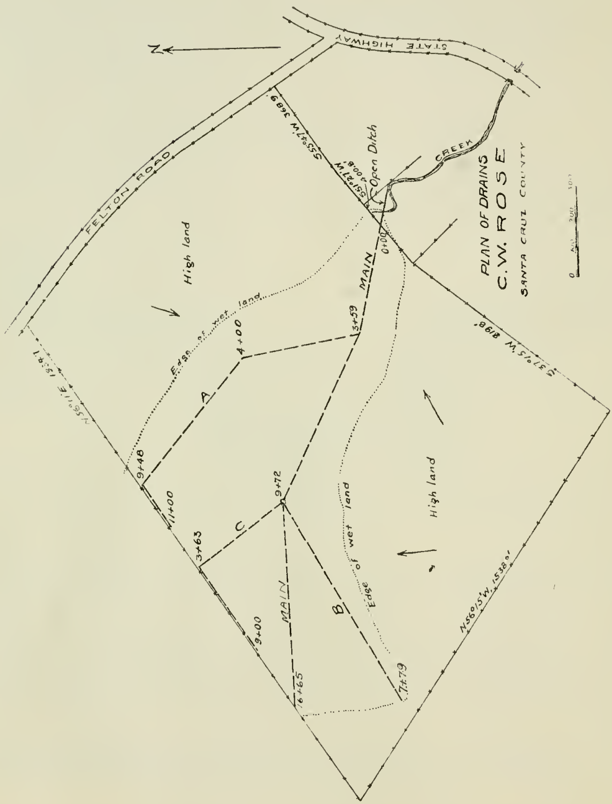

Fig. 5.—An area of swamp land drained with tile laid out according to the natural system.

the spacing. Figure 6 illustrates this point. In soils ranging from a sand to a sandy loam, drain lines may be placed from 150 to 300 feet apart; while in heavy silts and clays it may be necessary to place the lines as close together as 30 or 40 feet. Experience with soils of the same texture in the same locality is the best guide for spacing. Tile drains spaced as far as 150 feet apart and 3½ feet deep have given satisfactory drainage in some instances in California where the soils are comparatively heavy.

Grade.—The more fall that can be secured, other things being equal, the more rapid will be the drainage and the smaller the tile necessary to carry a given amount of water. The necessity for accurately determining

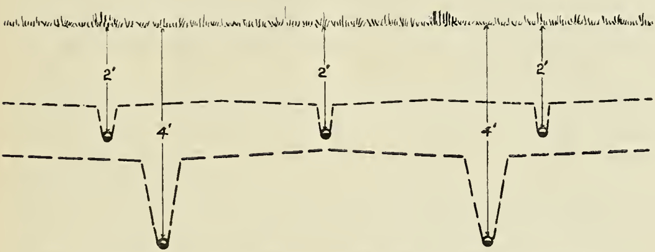

Fig. 6.—The relation between depth and spacing of tile and the area affected.

the grade on which tile are to be laid should be emphasized. This is especially true when the grades are flat. It is not so important that any particular grade be secured, but it is important that the grade, whatever it is, be known and that the tile be carefully laid to conform to it. More than one grade is frequently used on long tile lines. This is known as a "broken" grade. Whenever a grade is flattened, it must be compensated for by an increase in the size of the tile. Whenever possible, the grade should be made steeper as the outlet is approached. Such a condition is a reasonable assurance that particles of soil which may enter the line will be carried on to the outlet instead of settling in the line with the danger of clogging it. It more often happens that grades must be flattened toward the outlet, because of the topography of the land.

A fall of 1 foot per 1,000 feet, or a grade of $\frac{1}{10}$ of 1 per cent, is about as flat as it is advisable to use, although some successful drains have less. A grade of 2 to 5 feet per 1,000 feet is very satisfactory for tile lines and very little difficulty will be encountered either in construction or maintenance where this can be secured.

It is sometimes said that one drain "draws" better than another or that the "draw" is of such and such a distance. Actually drains do not draw

at all in the sense that they pull or suck the water from the soil. Underdrains serve only as collecting channels or outlets for the water which reaches them by gravity. If one field drains farther back from the lines of tile than another, it is because the soil conditions are such that there is a more ready lateral movement of the underground water to the tile in one case or that the tile is of insufficient capacity to remove the water as rapidly as it reaches it in the other.

Discharge or Runoff.—The size of tile necessary to drain a tract of land is based on two considerations, the fall or grade on which the tile can be laid, and the amount of water or runoff which it has to carry. The grade can be accurately determined, but the runoff is not so easily obtained. Drains are usually spoken of as having a capacity to remove in 24 hours some definite amount (¼, ½, or 1 inch) in depth of water from the area to be drained.

The amount of water which will reach the drains in a given time is dependent upon the character of the soil, the intensity and duration of rainfall, the size of the area, and to some extent, the shape of the area.

In clay soils, water reaches the tile more slowly than in sand; therefore the tile may be smaller in clay, although during the season as much water may be removed from one soil as from the other. Open drains, especially those designed to take care of surface flow, must be built of a size capable of handling the maximum runoff. At times this may amount to a considerable proportion of the heaviest rains. It sometimes happens in the coast sections of California that a steady rain lasting for several days will be followed by a very heavy downpour, most of which will run off as surface water. In normal years this may occur once or twice during the winter season.

For tile drains the maximum 24-hour rainfall is not so important as the maximum duration of any one storm. Long continued rains which permit the water to penetrate into the soil rather than flow from the surface usually cause the greatest discharge in tile systems. It is seldom that underdrains are necessary which have a larger 24-hour carrying capacity than ½ to ⅝ inch in depth from the area drained, although occasionally a runoff of 1 inch may be obtained. For large areas the rate of runoff at the outlet is smaller than for small areas. The same is true for long, narrow areas as compared to areas more nearly square, because water from the more distant sections does not reach the outlet until after that from nearer points has passed on.

The amount of water to be carried in a drainage system cannot be exactly foretold as each case presents its own local peculiarities and experience is the best guide. An approximate estimate of the discharge is

necessary for a general guide, however, and the figures given will serve as a basis for such an estimate.

Size of Tile.—When the maximum amount of water to be carried has been decided upon and the grade upon which the drain can be constructed is known, the size of the ditch or tile necessary is largely a matter of computation. There are a few general principles, however, which do not conform strictly to the mathematical computation of tile size.

It is never advisable to use tile smaller than 4 inches in diameter, even for short laterals; in fact, some tile factories have discontinued the making of drain tile less than 4 inches in diameter. Even with the greatest care irregularities in the grade or laying of the tile are sure to occur. A slight irregularity in a line of small tile has a much more serious effect on its efficiency than does a similar irregularity in a line of larger tile.

Tile 4 and 6 inches in diameter (preferably 6) may ordinarily be used for lateral drains 1,000 feet or less in length, whereas, 6- and 8-inch tile may be used for submains and the upper ends of mains. Some factories make the intermediate sizes, 5- and 7-inch, which can of course be used in their proper places.

Except for small areas, it is not necessary to make the capacity of the main drain equal to the combined capacities of the laterals. Lateral drains are seldom required to carry their full capacity; in fact, a drain that runs full for a considerable time may safely be considered too small.

The difference between the cost of a drainage system using 4-inch tile and of one using 6-inch tile for laterals, lies almost entirely in the cost of the tile itself, which is seldom more than 30 or 35 per cent of the entire cost of the system. The smallest trench that it is practicable to dig by the methods usually employed in California will be large enough for 6- or even 8-inch tile. There is not enough difference in weight between a 4-inch and a 6-inch tile to add materially to the cost of laying, and the cost of backfilling will be the same in both cases. Furthermore, incidental expenses do not increase in direct proportion to the size of tile used. To be of the highest efficiency, the tile must be of sufficient size to remove all surplus water before the crops are injured, even after the heaviest rainfall in a continued wet period.

The diagram shown in figure 7[2] may be used as a means of determining the size of the tile necessary when certain facts are known. For example, suppose the estimated runoff is 5/8 inch in 24 hours from an area of 70 acres and the available fall is 2 feet per 1,000 (or .2 foot per 100), what

[2] The method used in computing the formula for this diagram is fully described in: Yarnell, D. L., and S. M. Woodward. Flow of water in drain tile. U. S. Dept. Agr. Bul. 854:150. 1920.

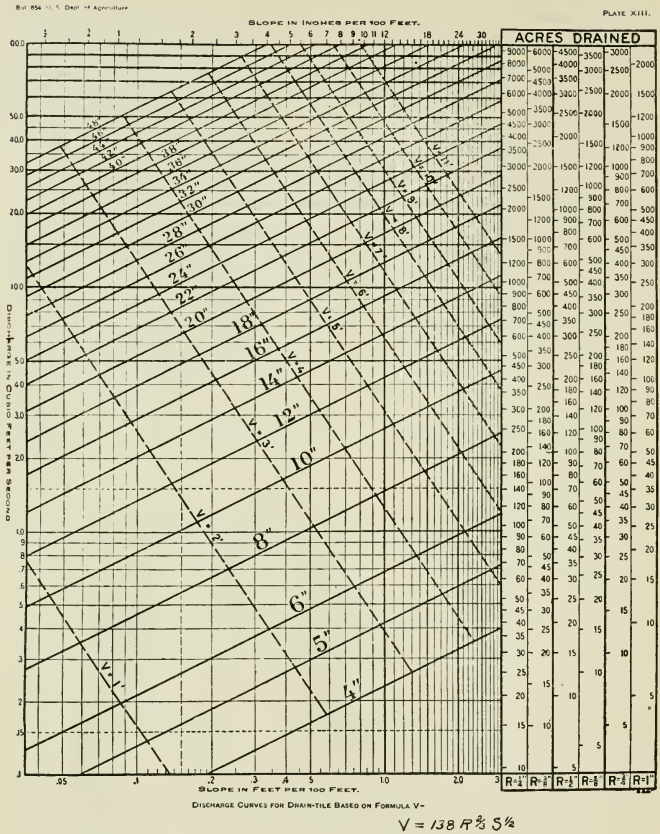

Fig. 7.—Diagram for computing the size of drain tile when certain factors are known.

size will the main drain need to be? In the third column on the right above the title "R = ⅝" will be found the area "70"; a horizontal line through this point intersects a vertical line through ".2" found on the bottom border of the table at a point just below the line sloping upward to the right marked "12," which represents the tile diameter. Thus, a tile 12 inches in diameter will be required. At the same time it can be noted that the discharge from this tile will be slightly under 2 cubic feet per

second (left-hand border), and the velocity of flow will be approximately 2½ feet per second (line sloping upward to the left). The use of a diagram saves a great deal of computation.

Kinds of Tile.—There are two kinds of tile available for drainage work in California, namely, clay tile and concrete tile. Both are used extensively, sometimes on the same system, and both are proving satisfactory when they have been well made from good material.

Clay tile is made in sizes varying from 4 inches to 30 inches in diameter, although some factories do not carry regular stocks in sizes greater than 18 inches. For the large sizes, sewer pipe is sometimes used. There is no objection to this other than it may be more expensive.

Clay tile should be straight, well burned and free from defects. Soft or porous tiles, either in clay or concrete, should be discarded as defective. Water enters a tile line at the joints between the separate tile lengths and does not pass through the walls of the tile itself.

Concrete tile can usually be obtained in a larger assortment of sizes than clay. Concrete tile should be true to form, hard, dense and thoroughly cured. Homemade tile is likely to be inferior in quality and its use should be discouraged unless the builder has a good knowledge of the principles of concrete construction. It is safer to purchase tile from a reliable manufacturer.

Reliable and established manufacturers of both clay and concrete tile are thoroughly familiar with the standard specifications for drain tile established by the American Society of Testing Materials and make a product which they guarantee to meet those specifications. The engineer or tile user should insist upon actual tests being made if there is any doubt whatever as to its quality. Specifications requiring tile to be made either of clay or concrete are not in themselves assurance that a good quality will be obtained.

CONSTRUCTION OF TILE DRAINS

Before any work is done, the lines along which the tile are to be laid should be staked out and plainly marked. This is usually done by setting a "guard" or "marker" stake, each 50 feet or 100 feet, upon which the distance from the outlet is shown. Close to each of these stakes another, known as a "hub" or "grade" stake is driven so that its top is flush with the ground surface (fig. 8). It is from the top of this latter stake that measurements of depth or "cut" are made. This stake must not be disturbed in any way until the tile is laid and tested. The required depth at each stake is either recorded on the marker stake or furnished the workman in the form of a table or profile. The nearer edge of the trench is

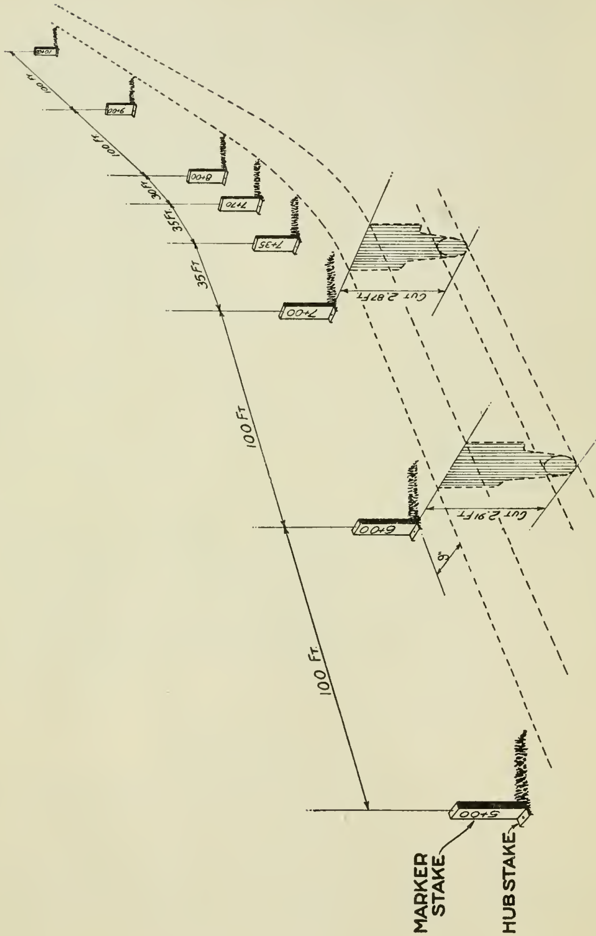

Fig. 8.—The method of laying out a drain.

laid off by the workman parallel to and about 9 inches from the line of stakes. This line should be marked with a stretched cord or by shovel marks on the ground so as to insure a straight trench.

Digging the Trench.—If there is much work to be done, a trenching machine may be used. For the type of drains described in this paper, the wheel type of trencher is the most common, but these machines are too expensive for the individual farmer to purchase. In some sections of the state, drainage contractors can be found who own trenchers and construct

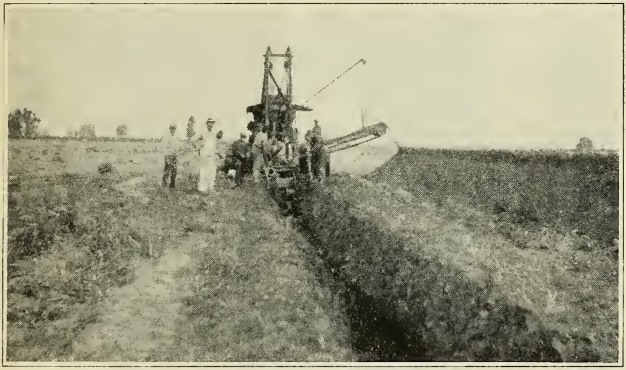

Fig. 9.—Drainage contractors use excavators which dig trenches rapidly and accurately and usually at less cost than the work can be done by hand.

drains for others at a stated price per foot or rod. A light ladder-type ditcher can be purchased as an attachment for small tractors. This machine, however, is rather expensive for the small farmer unless he contemplates doing work for others. Machine trenching is usually cheaper than hand trenching and has the great advantage of being more rapid. In figure 9 can be seen a wheel-type excavator at work.

For hand-dug trenches, one of the tile spades shown in figure 10 is the most satisfactory, where the ground is moist. This tool, however, is not very common in California. Often work is done during the dry part of the year when it is necessary to use a pick to loosen the soil. Work done at this time, however, is more expensive than when done at a time when the more convenient tools can be used. Digging should always start at the outlet so that any water that is encountered can drain away. Even when the ground is dry at the time of digging the trench, it is best to begin at the outlet. The trench, unless dug by machinery, should be finished to

within an inch or so of the bottom before the grade line is set. With machine-dug trenches a skilled operator can dig very close to grade at a single operation.

Establishing Grade.—It is very essential that tile be laid to the established grade. When tile drains become clogged or silted up it is very probable that they were not laid true to grade.

An easy method of determining the true grade at all points along the line is to stretch a light stout cord on crossbars directly over the trench

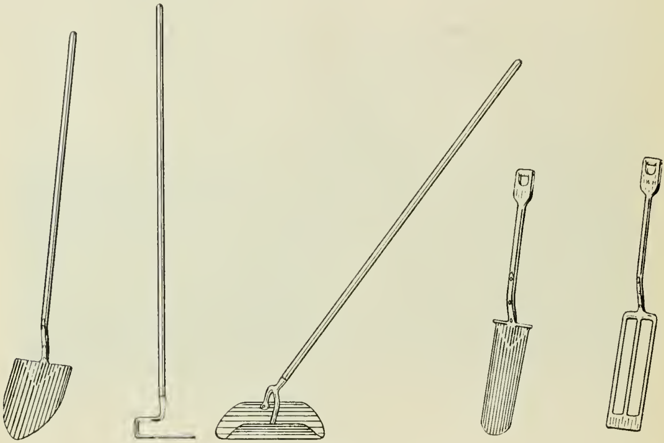

Fig. 10.—Tools used in constructing tile drains by hand.

and at some chosen distance, say 7 feet above the bottom. The crossbars are located at the stakes which have been set by the engineer. The leveled bars are placed at a distance above the grade stake equal to the difference between 7 feet and the cut or depth of trench at that point. A cord stretched across a number of bars so placed will everywhere along its length be 7 feet above the true bottom of the trench, which can easily be determined by measuring down from the cord at any point (fig. 11). Care should be taken to see that the cord is supported at intervals to prevent its sagging. When the grade cord is set the almost completed trench can be finished with a shovel and tile scoop.

Laying Tile.—It is presumed that the tiles have already been distributed along the line within easy reach from the trench. Small tiles can be placed from the bank with a tile hook as shown in figure 12. They should

be placed end to end as closely as they will lie in the trench. Tiles will occasionally be found whose ends are not cut squarely across, but by turning them slightly they can be made to fit closely.

Tiles larger than about 8 inches in diameter are placed by hand from the bottom of the trench, as they are too heavy to conveniently handle with the tile hook, and those over 18 inches in diameter are lowered into the trench with a block and tackle.

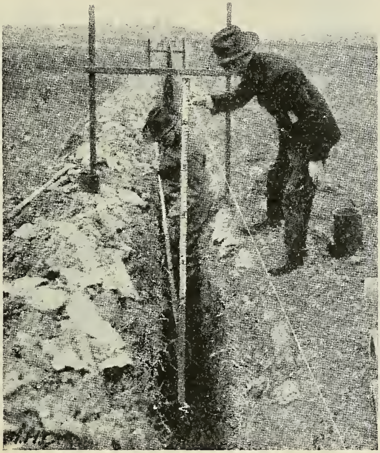

Fig. 11. Measuring down from an overhead cord to make sure that the bottom of the completed trench is everywhere seven feet from the line. (Courtesy of International Harvester Co.)

Tiles should receive a final inspection just before laying, as some may be damaged after they are brought to the field. Suspected tiles should be discarded; less harm will be done by discarding a good tile occasionally than by putting in a single poor one. One tile that fails after being placed may destroy the usefulness of the entire line above it.

As soon as the tile is in position, a little earth cut from the side of the trench will prevent its rolling out of line. After each 50 or 100 feet of tile is laid and at the end of each day's work, the tiles laid should be covered with earth to a depth of 3 or 4 inches so as to protect them from injury or dislocation by falling stones or chunks of earth. Sometimes in heavy soil, the first backfill or "blinding," as it is called, is done with soil

from the surface containing some sod or grass. A little straw, gravel, or rock may be used to keep heavy clay from packing too closely about the tile. If quicksand is encountered, these substances may be effectively used to prevent its entrance into the drain. These precautions, however, are necessary only in unusual circumstances.

Backfilling.—If the tiles are to be inspected by the engineer, such inspection should be done just before they are covered. The filling of the

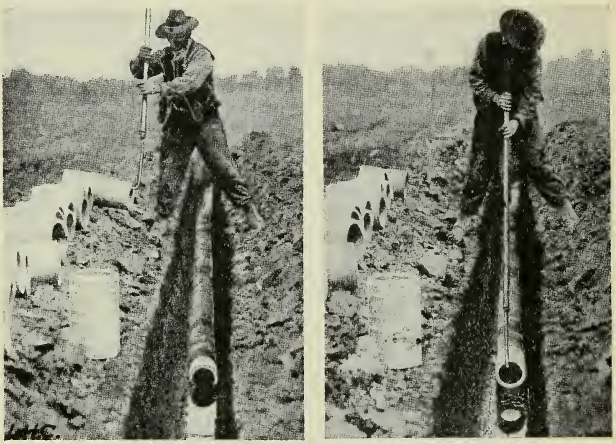

Fig. 12.—Laying small tile with a tile hook from the top of the trench. (Courtesy of International Harvester Co.)

trench can be accomplished in several ways. In places where the work is crowded, such as in an orchard or around buildings, the backfilling can best be done by hand with shovels. In the open field the soil is usually plowed into the trench. A long doubletree is provided so that one horse or one team is on each side of the trench. This method requires from two to three men and steady teams. Small slip scrapers or the large four-horse fresno scrapers are sometimes used, in which case the team works on the opposite side of the trench from the scraper (fig. 13). Power-operated backfillers are too expensive for the average farmer to own, but they are very desirable for the drainage contractor.

All of the earth excavated from the trench should be replaced; otherwise there will be a depression along the line when the soil settles.

BOX DRAINS

Box drains may be used when lumber can be secured at a reasonable price and tile is very expensive. The installation of box drains is similar in every respect to that of tile, and the same care should be used. Redwood lumber is much more durable than other kinds and should be used for all underground work in California. It is reasonable to expect redwood boxes to last for ten or twelve years; if kept wet during the entire year,

Fig. 13.—Backfilling a tile trench with slip scraper.

they will last much longer. In all cases, however, where lumber is used for underground work its life can be lengthened by treating with creosote.

Simple forms of boxes are shown in figure 14. The lumber for the smaller box (*a*) should run lengthwise. The sections may be from 12 to 16 feet long if the trench will remain open, without caving, for that distance. The top is nailed tightly to the sides, but the bottom is held away from the sides by short pieces of lath placed at intervals of 3 or 4 feet; this permits entrance of the water. In boxes with interior dimensions greater than 8 inches square, 2-inch lumber should be used and the top and bottom put on crosswise (*b*). In large boxes for main drains, the lumber for the top, bottom, and sides should all run crosswise. The bottom pieces should be separated so that when the lumber becomes wet and swells it will not close all openings for the water. The use of box drains

without bottoms is not advisable, as the water is likely to undermine the sides and cause the box to settle. Furthermore, any roughness of the bottom of the trench will reduce the capacity of the drain.

STRUCTURES

Surface water should not be allowed to enter directly into a tile line unless some provision is made to exclude sand, dirt, sticks, and other rubbish. Figure 15 shows two methods of screening surface water before it

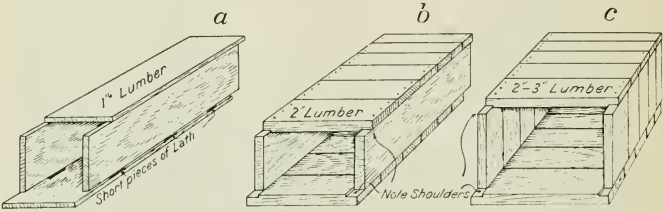

Fig. 14.—Types of lumber box drains.

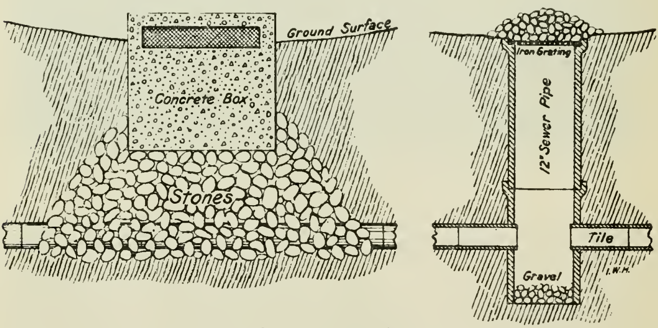

Fig. 15.—Surface inlets with screens.

enters a drain. One consists of a concrete box with an open bottom resting on a bed of stones which covers the tile. Water enters the box near the top through wire screens. The wire screens keep large particles, such as leaves and sticks, from entering the box and the stone filter removes sand and finer particles from the water before it enters the tile line. The other device is made from sewer pipe through which the water passes to enter the line. A heavy iron grating covered with small stones will prevent the entrance of anything except the water. If there is a considerable quantity

of water, the stone filter should extend over a greater length of tile than shown. The types of screen shown in this figure admit water readily to the tile line, but when placed in open fields are an obstruction to cultivation.

It is good practice to install silt boxes at intervals along a tile drain to catch and retain any silt that may enter the line. These boxes may be

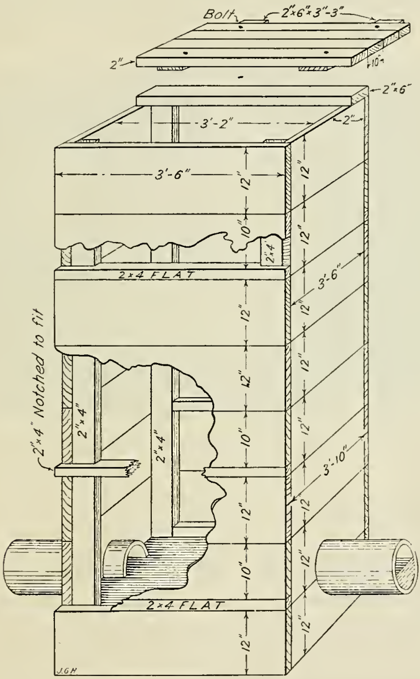

Fig. 16.—Combination manhole and silt box with cover.
(After D. G. Miller.)

made of lumber, concrete, or brick. A very satisfactory combination silt box, manhole, and observation well of lumber is shown in figure 16. It is inadvisable to construct silt boxes so small that they cannot be readily entered and cleaned. They should be placed at points where the grade changes to a flatter one, or where there are abrupt changes in the direction of the line. The junction of two lines is easily effected through such

a box, although in the gridiron or herringbone system of drains it would not be advisable to place a box at each junction.

The outlet of a tile drainage system, unless very favorably located, should be protected by some device which will prevent the tile from washing out or becoming injured or displaced. The outlet protection may be made of lumber, stone, brick, or concrete, the design depending upon the conditions which exist at the outlet. In any case care should be taken to secure a good foundation and anchorage so that the structure will not

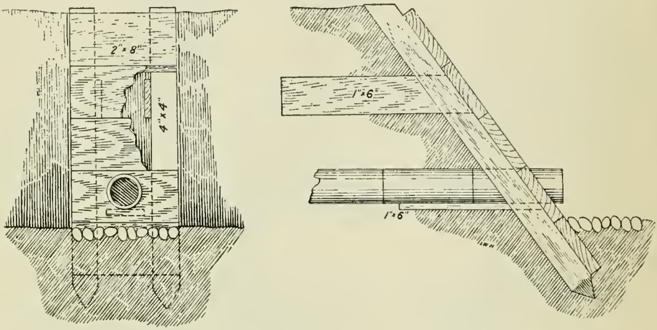

Fig. 17.—Timber outlet protection for small tile.

be undermined. Figure 17 shows an outlet protection for small tile, and the illustration on the front page of this circular shows a more elaborate outlet for a large main drain. The construction material used in making silt wells may also be used for outlet protections.

MAINTENANCE OF TILE DRAINS

Properly installed tile drains require very little maintenance. The silt boxes should be inspected frequently during the first year and at regular intervals thereafter, and should be kept free from silt. The covers of silt boxes should be kept closed and locked at all times (fig. 18). Tumbleweeds, rabbits, and squirrels may enter the silt boxes and obstruct the tile lines unless this precaution is observed.

Soil will not seal the joints and prevent the entrance of water into the tile lines under ordinary conditions. There need be but little fear of the roots of fruit trees growing into a tile line unless the tile carries water when the surrounding soil is dry. Such a condition would exist when the drain taps a spring which flows long after the surrounding area has become dry. Cottonwood and willow trees, however, should not be allowed

to grow within 50 feet of a tile line, as they are water-loving trees and frequently cause serious trouble.

Should a tile line become obstructed in any way, silt boxes located at frequent intervals will aid materially in locating the obstruction. A number of devices have been developed for cleaning sewers which can be used for drain tile. These may also be found useful during construction, especially if the tile is laid in a wet, muddy trench. The most common form of tile cleaner is one whose several sections can be jointed together when

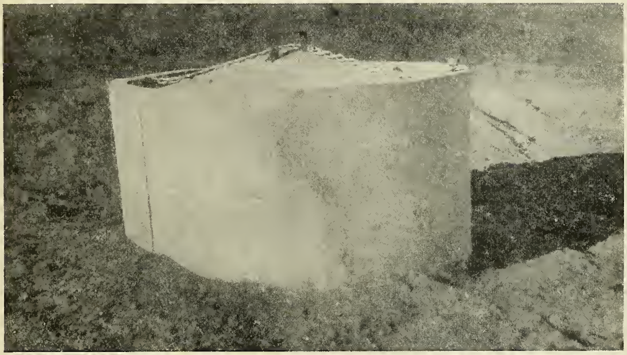

Fig. 18.—A manhole made from large concrete tile and having a metal cover securely fastened with a heavy chain and padlock.

the rods are held at right angles, but cannot be unhooked when extended. These rods may be used with or without any of the various attachments such as an auger, wire brush, hoe, or spiral cutter. A very simple brush can be made by wrapping a piece of leather belting around a cylindrical rod, the belting first having been driven full of wire nails of such a length that the completed brush will not quite fill the tile. Care must be exercised not to use fixtures that may become detached or will catch on the tile. As much as 250 feet of rod can be operated in a straight tile line.

COST OF DRAINAGE

The matter of cost is probably the most important item in drainage; upon this depends the feasibility of any undertaking. The engineer who has planned a system should be able to estimate the cost of it very closely. Unless the details of construction are known, however, only general and approximate cost data can be given.

There are only a very few factories on the Pacific Coast which manu-

facture clay drain tile exclusively, most of it being made to order or as a side line by clay-products factories. Cement-tile plants are more numerous, as practically the same equipment is used for the manufacture of drain tile as for irrigation pipe.

Tile is sold by the foot or the 1,000 feet, with discounts on carlots. Tile, both clay and concrete, is higher priced in all of the western states than

TABLE 1

WEIGHTS AND PRICES OF DRAIN TILE

Size	Clay		Concrete	
	Price per foot	Weight per foot	Price per foot	Weight per foot
Inches	*dollars*	*pounds*	*dollars*	*pounds*
4	0.05 to 0.08	7	0.05 to 0.08	9
6	0.08 to 0.13	11½	0.08 to 0.13	18
8	0.14 to 0.22	19½	0.14 to 0.18	27
10	0.20 to 0.30	32	0.18 to 0.26	36
12	0.28 to 0.38	40	0.25 to 0.35	42
14	0.35 to 0.51	50	0.33 to 0.42	64
16	0.45 to 0.60	60	0.40 to 0.55	85
18	0.60 to 0.90	100	0.65 to 0.75	102
20	0.90 to 1.10	138	0.75 to 0.90	120
22	1.25 to 1.55	150	0.90 to 1.10	145
24	1.60 to 1.90	165	1.10 to 1.25	170
26	2.00 to 2.50	200	1.50 to 1.75	210
28	2.50 to 3.00	235	1.90 to 2.50	250
30	3.00 to 3.50	265	2.50 to 3.00	277

in the East or Middle West. Table 1 may be used as a general guide to the price of drain tile at the factory, and the weights given may be used as a basis for figuring freight charges.

Both price and weight, however, may vary from the figures given. Frequently prices are quoted on pipe delivered at the rail point nearest the consumer or along the trench by truck.

Excavation of hand-dug trenches will cost, at the present price of common labor, from 40 to 60 cents an hour, from 10 to 20 cents a lineal foot for depths of from 3 to 5 feet and width sufficient for 8-inch tile. The cost varies somewhat with the season, the condition of the soil, and the amount of labor available.

Machine-dug trenches under favorable conditions will cost about one-half as much as hand-dug trenches.

Laying and backfilling will vary somewhat, but for the smaller sizes of tile will probably cost from 3 to 5 cents a lineal foot. This will bring the cost of a completed 6-inch drain to about 30 cents a foot. It may be roughly estimated that the cost of tile is from 30 to 40 per cent of the cost of the completed system.

DRAINAGE OF PEAT SOILS

Peat soils, such as are frequently found in small areas throughout the coast region and in the foothills of the Sierras, often require a system of drainage different from that of other soils. Peat is formed by the decaying vegetation that grows in the presence of an abundant water supply. It is often found surrounding or just below a spring or permanent seepage area. For the drainage of these soils, it is essential that the source of the water be found and the water intercepted.

Peat shrinks and settles markedly when drained, and the tiles are likely to become misplaced unless some precautions are taken to prevent it. If the peat is not too deep, the drains may be laid directly on the subsoil. If, however, the peat is too deep for this, it may be necessary to support the tile on a cradle made of lumber. Where the depth of the peat is irregular, a cradle is sometimes used to support that part of the drain which does not rest on solid subsoil. The cradle consists of two boards, usually 1 × 3 inch material, laid parallel and about 3 inches apart. These are laid flat and held together by cleats on the underside; sometimes the whole cradle is nailed to posts driven in the bottom of the trench.

Peat soils cannot usually be drained as deeply as others, because the capillary rise of water through them is very slight, and, unless irrigation is available or the water table is relatively close to the surface, crops may suffer from drought. Peat-land crops are of necessity, therefore, shallow-rooted.

DRAINAGE OF TIDAL MARSHES

In the drainage of tidal marshes, it is usually necessary to protect the land from tidal inundation by means of levees, and the drainage water is discharged through tide gates or pumping plants. The designing of these are, however, not within the scope of this circular. Most drainage for reclaimed tidal marshes in California has been of the open-ditch type, but the use of tile may prove to be more efficient.

The soils are usually very heavy-textured and contain large quantities of salt. Drains from 3½ to 4 feet in depth and spaced from 50 to 100 feet apart are proving satisfactory. It is necessary to keep the outlet drains, which are usually open ditches leading to the gates or pumps, as nearly empty as possible, so that the lateral drains will operate freely. Except for seepage through the levees, which is collected in an open drain just inside the levee, the runoff for tidal marshes is about the same as from similar-sized areas of adjacent uplands. Tidal marshes usually have no natural fall, and the grades for tile must be made by placing them shal-

lower at the upper end than at the lower. Care should be taken to have the upper ends deep enough to provide adequate drainage, even though it may mean that the lower ends are deeper than would otherwise be necessary.

VERTICAL DRAINAGE

By vertical drainage is meant the passing of surface drainage water vertically through the soil into a porous bed of sand or gravel beneath; it is effected by means of wells or pipes extending into the porous substratum. Vertical drainage is feasible only when the surface soil is underlaid by an impervious layer of clay or hardpan, beneath which is a porous layer of sand or gravel, which contains no water, or affords a channel through which the water may escape. Such a set of conditions is rarely found. The hardpan is usually underlaid by a nonporous subsoil filled with water which does not flow away. It would be useless to attempt vertical drainage if the subsoil were not porous, even though it were dry, because its water-holding capacity would soon be reached, and the drain would then become inoperative.

Vertical drainage, where practicable, may be accomplished by boring an 8- or 10-inch hole well into the porous stratum and lining this hole with ordinary drain tiles set one on top of another. The top must be securely covered and screened so as to prevent the entrance of silt or trash into the drain. Another method of accomplishing vertical drainage where the impervious layer is hardpan is to break up the impervious stratum with dynamite. If this method were used on a layer of clay, the clay would have a tendency to puddle back into an impervious layer, and instead of breaking and shattering, would pack and burn at the point of the explosion.

Every instance of contemplated vertical drainage should be thoroughly examined, as subsoil conditions will almost always be found unsuited to this type of drainage.

COÖPERATION IN DRAINAGE

It is seldom that a farmer can install an extended and comprehensive drainage system without coöperating to some extent with other landowners. Coöperation is often necessary to obtain an outlet. The right to drain land should not be abridged by the prejudices of an adjacent land owner. The rights of those owning lower lands which must be crossed by the drains of another must not be ignored, however, and if any injury whatever is sustained it should be paid for. As a matter of fact, a drain usually benefits the lower land by crossing it, and some arrangement

should therefore be made whereby the cost of such a drain will be borne by both parties. These matters should be amicably settled before work is begun.

When there are a number of persons interested in any particular drain or system of drains better coöperation can be secured through the organization of a drainage district. This provides a means of securing a comprehensive and well-planned system, and facilities financing. California is now adequately supplied with statutes covering this subject. The organization of a drainage district should not be attempted without the assistance and advice of an attorney to make certain that the proper procedure is followed.

DRAINAGE OF IRRIGATED LANDS

Although this circular, as stated in the introduction, is intended for use in nonirrigated areas, a brief discussion of some of the problems involved in the drainage of irrigated and alkali areas will be found in the following paragraphs.

Poor drainage conditions in irrigated areas are usually caused by the use of more water than can be transpired by plants or lost by evaporation. Whether this water comes from that actually applied as irrigation or as the result of seepage from canals and higher irrigated areas is not material to this brief discussion.

Many poorly drained irrigated areas are composed of light- to medium-textured soils in contrast to the heavier soils in nonirrigated areas and loss of water by seepage or deep percolation may be excessive.

The accumulation of alkali and soluble salts in irrigated areas often causes considerable damage and may materially restrict land use in a manner not encountered in humid areas. The whole drainage problem becomes involved and its solution may not be limited to removing the excess water.

In general, drainage must be deeper than in humid areas because, first, the soil is deeper and plants have deeper rooting systems; and, secondly, the water table must be kept below a point from which moisture can rise to the surface by capillarity and thus deposit alkali on the surface. Drainage depths in irrigated areas usually run from 6 to 10 feet.

The increased depth and lighter-textured soils permit the use of drains spaced further apart than is usual in humid sections but at the same time the amount of water collected per unit length of drain may be greater. Since poor drainage may be the result of community irrigation or seepage from community-owned irrigation systems the reclamation of such

lands may likewise involve community or district effort. Improved drainage may sometimes be accomplished by improved irrigation practices, prevention of seepage, or other related efforts.

Where alkali is a problem, drainage, although essential, may be only the first step in reclamation since the lowering of the water table to satisfactory depths may not in itself be sufficient to remove the alkali from the surface. The removal of alkali may involve leaching the soil with water, either with or without some chemical treatment, before reclamation is complete. It is not intended that this circular offer suggestions in alkali reclamation and the reader is advised to seek further information on this subject from the Agricultural Experiment Station.

Although the fundamental principles of drainage for irrigated lands are the same as those for humid sections, the requirements occasioned by deeper drains, lighter-textured and deeper soils, alkali reclamation, and by the necessity of community action, may materially modify the details of design and construction of drainage systems.

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